

# Meshed power system reliability estimation techniques

S. A. Gusev, O. M. Kotov & V. P. Oboskalov  
*Ural Federal University, Russia*

## Abstract

Electrical power system (EPS) reliability indices (RI) are calculated at both the operating and planning stages of power system operation. RI calculation is the key concern for power reserve estimating and dispatching, validating the new generation capacity and tie line installations, basic facility maintenance planning, selecting distribution substation key diagrams and local power system connecting diagrams and specifying the energy and power charges. The primary barrier to fast RI calculation is a meshed and hierarchical structure of a power system, the analysis of which is more of a challenge for an engineer. Additionally, there are a number of issues concerning the probabilistic nature of RI. This paper presents novel mathematical algorithms that have been developed at the department of automated power systems (DAPS) of the Ural Federal University.

*Keywords: reliability indices, power system security, power system adequacy, structural reliability, simultaneous failures, stochastic network reduction, Monte-Carlo Simulation, n-1 criterion.*

## 1 Introduction

Calculation and procedural problems concerning EPS reliability estimation are always relevant due to the variable nature of a power system. The power system always changes its structure, grows, develops and becomes more complicated, which determines the necessity of developing and renewing reliability estimation techniques and algorithms. Notwithstanding dynamic development of the reliability theory in the 1980s [1–5], there are still a lot of problems connected with reliability estimations, such as robustness and calculating the speed of estimating procedures. Moreover, there are a number of procedural problems, for instance, how many simultaneous failures should be considered in the model in order to get an adequate result.



Given the probabilistic nature of phenomena studied, the reliability theory is based on mathematical theory of chances. However, distribution functions (DF) used in the theory of chances are applicable to EPS, with several exceptions though. Therefore, a stochastic simulation problem arises, that aims to choose appropriate distribution functions and formulate calculating procedures obtaining final bounds. In addition, almost all scientists working in the field of reliability have to face stochastic network reduction (SNR) problems [4, 5].

It is possible to point out three types of reliability, depending on system of assumptions and an applied mathematical tool: diagram reliability (structural reliability), regime reliability (security) and balance reliability (adequacy).

In terms of structural reliability (SR), there is no failure if at least one conducting path connecting the power supplying node with the node under analysis exists. In other words, it is assumed that tie capacities are unlimited. Also, security restrictions, such as voltage bounds, are ignored. At this moment, most problems concerning SR are solved. Scientists at the DAPS have developed software named “STRUNA” [6]. It is based on the SNR technique [7] and allows calculating structural RI in real time.

Another research line at the DAPS is adequacy. It aims to optimize power reserve (spare capacity) [8, 9]. Adequacy calculations are necessary to justify investments into network elements and generators. It is well-known that first reliability investigations were associated with balance reliability (BR). In spite of this fact, there are still a lot of problems concerned with adequacy. General research line in the sphere of balance reliability at DAPS is also the stochastic network reduction.

At this moment, security calculations made at the DAPS are concerned with state estimations for all contingency situations (full contingency search) according to (n-m) criteria [10], where, in general, the number of simultaneously failing elements (SFE) m, equals up to the overall number of elements (the sum of nodes and branches) in the network (n). Nevertheless, in practice, it isn't necessary to analyze all possible contingency situations. As a result, another research line of the DAPS is associated with development of fast calculating algorithms and adoptive estimation of the significant number of simultaneously failing elements (SNSFE).

## 2 Structural reliability

All the experience of the DAPS in SR is unleashed in software “STRUNA”. This software is used to estimate SR of backbone and distribution networks, switchgears of power stations and substations and other network objects. As a result of its calculations, “STRUNA” creates a set of quantitative reliability indices, describing reliability of any network object. This set includes probabilities and intensities of failures and, also, lost load damage (LLD) and its expectation value (EV). The calculation algorithm, implemented in “STRUNA” is presented in figure 1.

SR in its traditional formulation has several problems that will be considered in this paper.



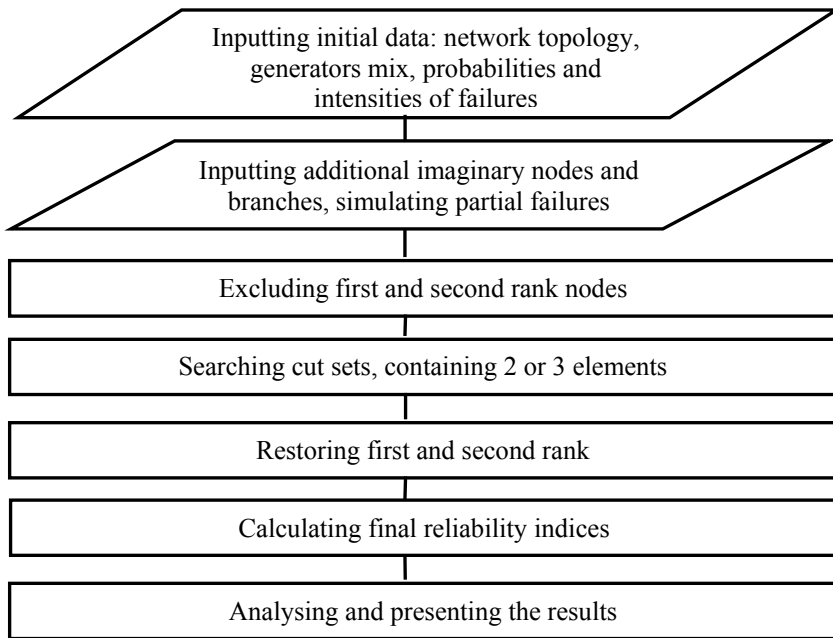


Figure 1: “STRUNA” calculating algorithm.

The key concern in SR is differentiation of failures into two types: a short circuit failure type (SCFT) and a breakage failure type (BFT). The first type is handled by reconstructive repairs, while the second type is handled by routine switching. For instance, SCFT includes failures, associated with circuit breaker failures in fault isolating. “STRUNA” takes SCFT into account through intensity of failures [7].

Another important issue concerning SR is the orientation of energy flows. If this issue is ignored, reliability indices of high-voltage power system are estimated to be higher than their real value, due to backup from the low-voltage power system. In order to take orientation of power flows into account, scientists at the DAPS have developed an oriented stochastic network reduction technique [7].

The third SR problem is concerned with the lack of possibility to account for partial failures by traditional approaches. This paper presents an algorithm, which allows accounting partial failures.

Indeed, traditionally, SR allows simulating only full nodal failures. However, it is possible to account for partial failures by enlarging initial data with additional imaginary nodes. This algorithm will be explained using an example.

Assume the sample power substation presented in Figure 2 to have a feedthrough load of 30 MW, own load of 30 MW and two transformers of 15 MW capacity each.

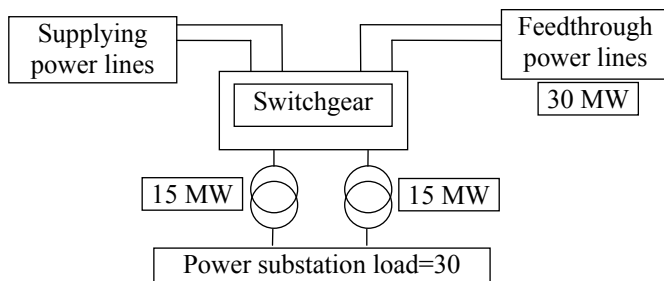


Figure 2: Sample power substation.

Partial failure occurs when one of the transformers fails. In this case, part of load is supplied, but another part is disconnected. Taking into account transformer overload capacity, which, in general, is about 1.4 of nominal rating power, 21 MW of the load can be supplied by one transformer. Therefore, when one of transformers fails, 9 MW of load are being cut off. This situation may be presented as it is shown in Figure 3.

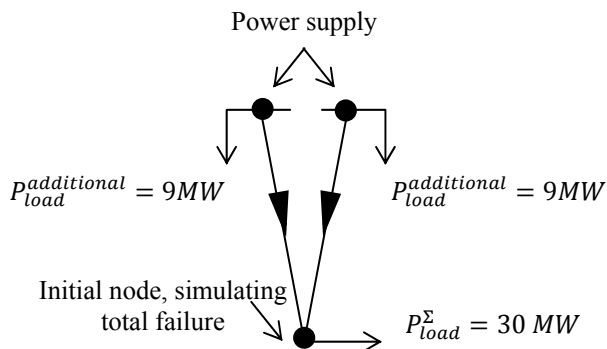


Figure 3: Modified node model.

As it is seen from Figure 1, in order to take partial failure into account, it is possible to add 2 imaginary nodes with additional load of 9 MW, which is connected with the initial node through oriented branches. As a result, full failure of each additional node equals to partial failure of initial node. Moreover, full failure of the initial node doesn't impact additional nodes, thus RI of such failure remains the same as in the initial model.

As an example of a practical application of the proposed model, a number of sample substation key diagrams [8] were compared. The following key diagrams may be recommended [8] for the power substation presented in Figure 2: 8 (hexagon), 9 (one sectionalized operating busbar), 9H1 (one sectionalized operating busbar with transformers connected through the breaker bifurcation), 9H2 (one sectionalized operating busbar with feedthrough power lines connected through the breaker-containing bifurcation), 9AH (one sectionalized operating

busbar with important “one and half” diagram-connected feeders). The comparison criterion was the EV of LLD. Table 1 shows the LLD EV corresponding to both partial and full failures.

Results, presented in Table 1 allow ranking the analyzed key diagrams in terms of their reliability. Diagram 9H2 has the lowest LLD EV of its own load full failure, while diagram 9H1 has the lowest LLD EV of the feedthrough load full failure. Diagram 9AH has the lowest LLD EV of its own load partial failure. Moreover, diagram 9AH has the lowest total LLD EV, therefore it may be recommended for analyzed power substation.

Table 1: Lost load damage expectation value.

Key diagram	8	9	9H1	9H2	9AH
Simultaneous failures of transformers	0.2397	0.3181	0.2358	0.1689	0.2397
Simultaneous failures of feedthrough power lines	0.2397	0.3181	0.2358	0.3155	0.2404
Summarized LLD EV of simultaneous failures, MWh	0.4794	0.6362	0.4716	0.4844	0.4801
Summarized LLD EV of simultaneous failures, relative units	1.0165	1.3490	1.0000	1.0271	1.0180
Failure of one transformer	2.203	9.878	9.423	5.871	2.201
LLD EV of partial failures, relative units	1.0009	4.4880	4.2812	2.6674	1.0000
Total LLD EV, MWh	2.6824	10.5142	9.8946	6.3554	2.6811
Total LLD EV, relative units	1.0005	3.9216	3.6905	2.3704	1.0000

### 3 Balance reliability

From a mathematical point of view, the main goal of adequacy is to identify probabilistic characteristics (such as DF, frequency, EV, variance) of power (or energy) shortage in a separated concentrated power system connected with other systems through tie lines with limited capacity. Basing on these characteristics, it is possible to calculate LLD EV, hence, to solve the investment problem.

In general, initial data for the BR problem is as follows: EPS topology, structure and probabilistic characteristics of generators and tie lines, load characteristics, commissioning, decommissioning and overhauls schedules. The key concern here is maintenance schedules. There are two ways to form them. The first implies planning overhauls and medium repairs as part of the united calculating procedure aimed to define both operating and contingency reserves. Another way is to schedule overhauls and medium repairs immediately before calculating adequacy indices. The second way is used by almost all adequacy software. However, for a long-term planning, when load has high uncertainty, the second way should be preferred [9].

Similar generating units are grouped into blocks with binominal probability distribution of their states. Hereafter these groups are united in probabilistic sequence [10]. As a result, different groups of generators are being integrated into one equivalent group [1, 13]. In addition, resulting probabilistic sequence is often approximated by certain continuous distribution, such as normal, gamma, etc. [9]. In general, the type of approximating distribution depends on load probability distribution, which is the most significant stochastic variable. This approximation causes a simulation error and should be substantiated for each simulation.

Tie lines are usually represented by capacity probabilistic sequences. In this case approximation of probabilistic sequences by continuous distribution is extremely inadvisable, due to a small number of line states (for one line only 2 states: on and off).

At the present day, the basic adequacy calculating technique for meshed EPS is Monte-Carlo simulation (MCS). It ensures reasonable accuracy if the statistical sample is large enough [13]. Practical experience shows good effectiveness of MCS for long-term calculations of network investments, when calculating time isn't very important.

More recently, however, emphasis in adequacy calculations has been made on analytical methods. First of all, this is caused by extension of BR calculations to the sphere of operational calculations. In this case, BR calculations, on the one hand, allow optimizing commercial and operating reserves, but on the other hand, require a fast calculation technique. For faster adequacy calculations, a reduced probability distribution technique is recommended [10]. Also, SNR technique is applied in MCS. For instance, a generating system is often represented as one equivalent generator, having binominal or Poisson probability distribution of failure-free operation, instead of a number of standalone generators having exponential probability distribution [14].

At this moment, there are no mathematical difficulties concerning BR calculations for radial structures of united power systems. These calculations may be performed by any of the above presented techniques. Most of BR calculation difficulties are associated with multiple-circuit networks of united EPS within explicit mutual aiding subsystems.

An adequacy problem may be represented as a problem of supplying demand for a capacity margin (CM), when load  $L_i$  and available capacity  $G_i$  have a stochastic nature. Then power imbalance (PI) in EPS  $i$  may be presented as follows:

$$N_i = L_i - G_i. \quad (1)$$

If  $N_i < 0$ , the system has available capacity and that may be provided to the interconnected system  $j$  through tie line  $i - j$ . The tie line has capacity in the forward direction  $\pi_{ij}$  and capacity  $\pi_{ji}$  in the backward direction.

Assume that each EPS has DF  $F_i(x)$ , EV  $\bar{N}_i$  and variance  $D_i$  of stochastic variable  $N_i$ . Denote the demand of EPS  $j$  for an available capacity of EPS  $i$  by  $N_{i(j)}$ . Due to the impact of other interconnected systems, EPS  $i$  has system demand:

$$N_i^S = \sum_{j \neq i} N_{i(j)}. \quad (2)$$

The system demand has DF  $F_i^S(x)$ , EV  $\bar{N}_i^S$  and variance  $\bar{D}_i^S$ . Taking into account the impact of other systems, summarized power imbalance in EPS is:

$$N_i^\Sigma = N_i + N_i^S.$$

If CM of tie  $i - j$  is limited by the interval  $(-\pi_{ji}, \pi_{ij})$  then the reduced probability distribution function PI defines as follows:

$$F_{i(j)}(x) = F_j^\Sigma(x, -\pi_{ji}, \pi_{ij}) = \begin{cases} 0, & x < -\pi_{ji}; \\ F_j^\Sigma(x), & -\pi_{ji} < x < \pi_{ij}; \\ 1, & x \geq \pi_{ij}. \end{cases} \quad (3)$$

The change in mutual aid or in PI results in the change of  $N_i^S$ . This change, in its turn, adjusts resulting probabilistic characteristics of all interconnected EPS. This fact determines interrelation of all interconnected subsystems. Calculating  $N_{i(j)}$  for every  $i$  and  $j$ , with account for subsystems interaction, gives a solution for BR problem. Nevertheless, at this moment, the problem in such a formulation may not be solved analytically.

In order to get a solution, it is possible to apply a capacity market model. According to this model, at the first stage, subsystems exchange available capacity with near subsystems. Then exchanging capacity is being adjusted, due to the impact of distant subsystems. The transient process goes on until it results in a certain steady state. Changes in mutual aid in this steady state are caused only by fluctuations of PI. In relation to BR problem, such exchanging process is defined by the following recurrence equation:

$$F_{i(j)}^{(k+1)} = \left( F_j^\Sigma(x, -\pi_{ji}, \pi_{ij}) \right)^{(k)}. \quad (4)$$

Convergence of the process in eqn. (4) depends on the way PI is redistributed. For instance, in a simple additive model, where, during calculation of  $N_{i(j)}$ , EPS  $j$  is presented by full PI  $N_j^\Sigma$ , it is possible that positive feed-back should occur. Indeed, in a circular structure with three interconnected EPS  $i, j$  and  $k$  PI  $N_{i(j)}$  increases PI  $N_i^\Sigma$ . It results in an increase of  $N_{(k)i}$ , therefore, an increase of  $N_k^\Sigma, N_{j(k)}, N_j^\Sigma, N_{i(j)}$ . At the same time, counter-current flow techniques, for instance, allocation of PI in proportion to the demand of the near systems, allow enhancing negative feedback, therefore, convergence of the calculating process. However, these techniques don't ensure the desired robustness, due to different proportionality factors for load and generation. This fact brings up a necessity to account load and generation impact separately. Nevertheless, at the level of a single EPS these variables are united, which breaks down the regulating phenomenon. In order to improve robustness of the calculating procedure, the supplied demand technique may be used.

The iterative procedure, presented by eqn. (4), results in the definition of PI in tie  $i - j$ . This PI is defined by the demand for a capacity margin both from EPS

$j$  ( $N_{i(j)}$ ) and EPS  $i$  ( $N_{j(i)}$ ). These variables form PI in tie  $i - j$ , but don't finally define it. PI in line is defined by the supplied demand, both from EPS  $j$  and EPS  $i$ .

The definition of PI is a multi-stage process. It is assumed, that at each stage of the calculation process, DF  $F_i^{\Sigma}(x)$  is known. In addition, it is necessary to know DF of the summarized power demand of EPS  $i$  any without impact of EPS  $F_{ij}^{\Sigma}(x)$ . This DF allows accounting impact of near subsystems in a proper way.

In a two-node network PI in tie  $i - j$  is defined by a difference between the demand of EPS  $j$ , supplied by EPS  $i$  and the demand of EPS  $i$ , supplied by EPS  $j$ :

$$N_{ij} = N_{ii(j)} - N_{jj(i)} \quad (5)$$

Distribution function of PI  $N_{ij}$  is as follows:

$$F_{ii(j)}(x) = \begin{cases} V_i(-x)F_{ji}^{\Sigma}(x), & x \geq 0; \\ R_i(-x)F_{ji}^{\Sigma}(x), & x < 0, \end{cases} \quad (6)$$

where  $R(x) = 1 - F(x)$  is an additional DF. In contrast with DF  $F(x)$ , function  $V(x)$  indicates, that stochastic variable  $\xi$  includes the right limit  $V(x) = \mathcal{P}\{\xi \leq x\}$ , when  $F(x) = \mathcal{P}\{\xi < x\}$ . This becomes important, when DF has a simple discontinuity, like DF of available capacity. On the other hand, when DF is continuous  $V(x) = F(x)$ .

DF of capacity margin being reduced by  $(-\pi_{ij}; \pi_{ij})$  has the following EV:

$$\begin{aligned} \bar{N}_{ii(j)} = M_j \Big|_{-\pi_{ij}}^0 &+ \pi_{ji}F_{ji}^{\Sigma}(-\pi_{ji})F_{ij}^{\Sigma}(\pi_{ji}) + \pi_{ij}F_{ij}^{\Sigma}(-\pi_{ij})R_j(\pi_{ij}) - \\ &- \int_{-\pi_{ji}}^0 xF_{ij}^{\Sigma}(-x)dF_{ji}^{\Sigma}(x) + \int_0^{\pi_{ij}} xF_{ij}^{\Sigma}(-x)dF_{ji}^{\Sigma}(x), \end{aligned} \quad (7)$$

where  $M_j \Big|_{-\pi_{ij}}^0$  is EV of DF  $F_j$  reduced by  $(-\pi_{ij}; 0)$ .

Eqn. (7) has integrals. It is desirable to derive an analytical expression of them. Generally, load is described by normal distribution (ND). Generation is described by binominal distribution, which asymptotically approaches ND, when the number of generators is increasing. Therefore ND may be a good approximation for the DF of PI. ND has an analytical expression for reduced EV. After analytical transformations and integration by parts, eqn. (7) will be as follows:

$$\begin{aligned} \bar{N}_{ii(j)} = M_j \Big|_{-\pi_{ij}}^0 &+ \pi_{ji}F_{ji}^{\Sigma}(-\pi_{ji})F_{ij}^{\Sigma}(\pi_{ji}) + \pi_{ij}F_{ij}^{\Sigma}(-\pi_{ij})R_j(\pi_{ij}) - \\ &- F_{ij}^{\Sigma}(-x)[M_jF_j(x) - \sigma_j^2f_j(x)]_{-\pi_{ji}}^0 - M_jF_{j+i|(0,\pi_{ji})}(0) + \\ &+ \sigma_j^2f_{j+i|(0,\pi_{ji})}(0) + F_{ij}^{\Sigma}(-x)[M_jF_j(x) - \sigma_j^2f_j(x)]_0^{\pi_{ij}} + \\ &+ M_jF_{j+i|(-\pi_{ij},0)}(0) - \sigma_j^2f_{j+i|(-\pi_{ij},0)}(0). \end{aligned} \quad (8)$$



Power imbalance  $\bar{N}_{jj(i)}$  is calculated similarly to  $\bar{N}_{ii(j)}$ . Hence, EV of tie PI may be defined without numerical integration. Eqn. (8) was verified by MCS technique. Results show that analytical solution is the marginal result for MCS, thus it is accurate enough.

The proposed technique has been tested on a sample system, having three subsystems A, B and C. All subsystems are connected by tie lines with capacity margin of 200 MW. Power imbalances in the subsystems are the following:  $N_A = -200$  MW,  $N_B = -400$  MW,  $N_C = 600$  MW. Root mean square deviation of all PI  $\sigma_i = 300$  MW. The calculating process converged in 4 iterations.

## 4 Regime reliability

Regime reliability (RR) defines capability of EPS to work without deviation of state parameters (SP) out of permissible boundaries, after random disturbances, such as failure of transformer, power line or generator. The failure occurs when SP, such as nodal voltages, power flows or thermal capacities, is out of permissible boundaries.

Security problem consists in simulation of possible failures and analysis of post-contingency states. If the failure results in SP boundaries violation, in order to recover permissible SP, it is necessary to implement control actions (CA). These CA may include adjustment of transformer ratios, actual and reactive generation, and the state change of static capacitor banks, static compensators and hydro generators. In the absence of spare capacity, it is necessary to cut off energy consumption. In this case, the optimal cutting problem is solved, according to the criterion of minimal LLD. Resulting damage, with a certain weighing coefficient defined by probability of the failure includes in EV of overall damage, which is one of the most important security indices.

At this moment security calculations are a mandatory procedure for a short-term and current EPS operation stages. Thus, RR problem results in multiple calculations of post-contingency states, where one or several elements are assumed to fail. The number of SFE depends on the calculating criterion  $n - m$ , where  $n$  is the total number of elements and  $m$  is the number of SFE.

Global experience shows the necessity to analyze post-contingency states in accordance with  $n - 2$  or even  $n - 3$  criteria [14]. This is determined by the fact that maximum of LLD EV, generally, corresponds to 2 or 3 simultaneous failures.

Simulation of simultaneous failures significantly complicates the security estimation procedure, due to the extremely increasing number of calculations. Indeed, the number of calculations increases in accordance with binomial coefficient:

$$C_n^k = \frac{n!}{k! \cdot (n - k)!}, \quad (9)$$

where  $n$  is the total number of network elements,  $k$  is the number of SFE.

Furthermore, the initially uncertain number of SFE complicates software implementation of calculating procedure, due to the uncertain number of nested loops, embodying simultaneous failures.

Full contingency search results in unreasonably high computing time. On the other hand, many contingency combinations have little impact on overall EV of LLD, due to the very low probability of such combinations. Therefore, it would be useful to estimate SNSFE. This value may be estimated, basing on maximum LLD criterion. EV of overall LLD is defined as follows:

$$D = \sum_{S_i \in S} \mathcal{P}_i D_i, \quad (10)$$

where  $S = \{S_i\}$  is a set of all possible contingency combinations;  $\mathcal{P}_i$  is the probability of combination  $S_i$ ;  $D_i$  is EV of state  $i$ .

Let  $D^{max}$  is the maximum damage, corresponding to the most unfavorable combination of SFE. In this case, the following inequality is valid:

$$D < D^{max} \sum_{S_i \in S} \mathcal{P}_i. \quad (11)$$

In the idealized case, when all network elements have the same failure probability  $q$ , for instance  $q = q^{max}$ , each combination may be defined by the number of failed elements  $k$ . Probability of such state defines as follows:

$$\mathcal{P}_i = C_n^k q^k p^{n-k}, \quad (12)$$

where  $C_n^k$  is binominal coefficient, defined according to eqn. (9).

Substituting of eqn. (11) to inequality (10) results in:

$$D < D^{max} \sum_{k=0}^n C_n^k q^k p^{n-k}. \quad (13)$$

The sum in the right part of inequality (13) may be presented as two sums, corresponding to significant and insignificant contingency sets:

$$D < D^{max} \left( \sum_{k=0}^m C_n^k q^k p^{n-k} + \sum_{k=m+1}^n C_n^k q^k p^{n-k} \right) \quad (14)$$

where  $m$  is SNSFE in significant contingency set.

Inequality (14) may be presented as follows:

$$D < D^{max} (B(m, n, q) + \tilde{B}(m, n, q)) = D^{max} B(m, n, q) + \varepsilon, \quad (15)$$

where  $B(m, n, q)$  is integral function of binominal distribution (IFBD);  $\tilde{B}(m, n, q)$  is co-function of binominal distribution (CFBD);  $\varepsilon$  is permissible damage calculation error (PDCE).

According to inequality (15) PDCE determines as:

$$\varepsilon = D^{\max} \tilde{B}(m, n, q). \quad (16)$$

Thus, permissible value of CFBD is defined as:

$$\tilde{B}(m, n, q) = \frac{\varepsilon}{D^{\max}}. \quad (17)$$

Eqn. (17) allows finding SNSFE  $m$  as probability quintile, meeting eqn. (17).

Several rude assumptions, connected with LLD EV and probability of failure, have been made during development of eqn. (17). A more precise solution may be obtained, using successive refinement technique (SFT).

In accordance with SFT, the first approximation of maximum LLD  $D^{\max}$  is calculated by the assumption that SNSFE  $m$  equals to two or three, depending on the analyzed network. This is based on the fact that, probably, maximum of LLD EV corresponds to two or three simultaneous failures. A new value of SNSFE obtained according to eqn. (17), corrects initial SNSFE and iterative calculating procedure runs again.

It's worth noting that branch failure probability is significantly higher than node failure probability. Thus, it may be reasonable to estimate SNSFE separately for nodes and branches and then find a weighted value of SNSFE, where the number of nodes (or branches) stands for the weight of node SNSFE (branch SNSFE):

$$m = \frac{m^{nd} n^{nd} + m^{br} n^{br}}{n^{nd} + n^{br}}, \quad (18)$$

where  $m^{nd}$  and  $m^{br}$  are the number of node and branch SNSFE correspondingly;  $n^{nd}$  and  $n^{br}$  are the number of nodes and branches in the network correspondingly.

The proposed technique was tested on the 14-bus IEEE reliability test system. Initial data was elaborated with element failure probabilities and node lost load damages. Failure probability was set to 0.01 and 0.1 for nodes and branches correspondingly. LLD for all nodes was set to 1 relative unit. Initial approximation of SNSFE was 2. As a result, node SNSFE was 2 and branch SNSFE was 5. Weighted value of SNSFE was 3.76. Since SNSFE is calculated according to maximum criterion, fractional part of SNSFE may be ignored. Therefore, with high degree of accuracy, it is possible to say that maximum of LLD EV corresponds to 3 SFE. Since resulting SNSFE was different from the initial, second iteration was necessary. At the second iteration node SNSFE was 2 and branch SNSFE was 6. The weighted value of SNSFE was 4.35. The third iteration didn't change the resulting SNSFE. So, the final value of SNSFE was 4.

The proposed technique was verified by full contingency search. Its results are presented in Table 2.



Table 1 shows that maximum of LLD EV corresponds to 3 SFE and SNSFE is 4. As a result, it is possible to say that the proposed technique is accurate enough for small networks with concentrated generation.

Table 2: The results of full contingency search.

Number of simultaneously failing elements	1	2	3	4	5
Lost load damage expected value, r.u. per year	270.98	839.21	1111.04	934.21	219.03

## 5 Conclusions

This paper presents general EPS reliability research lines at the DAPS. Scientists at the DAPS believe that most structural reliability problems are solved. However, this type of reliability has several noticeable assumptions, including partial failure impossibility. The paper presents an algorithm, allowing removing this assumption.

In contrast with SR, adequacy and security still have a number of calculation and procedural problems. The basic adequacy calculating technique for meshed EPS is Monte-Carlo simulation (MCS). For faster adequacy calculations, a reduced probability distribution technique is recommended. Also, a SNR technique is applied in the MCS. On the other hand, these techniques may have a positive feed-back of the calculating procedure, thus, convergence issues. In order to improve robustness of the calculating procedure, this paper presents the supplied demand technique. This technique was verified by MCS. Results show analytical solution obtained with supplied demand technique is the marginal result for MCS.

The key issue in security calculations is the number of simultaneously failed elements. Full contingency search results in unreasonably high computing time. On the other hand, many contingency combinations have a little impact on overall EV of LLD, due to the very low probability of such combinations. This paper presents technique estimating significant number of simultaneously failed elements almost without additional computational load. The proposed technique was tested on the 14-bus IEEE reliability test system. Results show adequate accuracy of the technique. Moreover, results confirm the necessity to simulate simultaneous failures of network elements.

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